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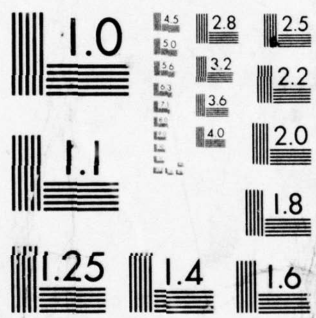

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THESIS

SOURCES AND BIOLOGICAL EFFECTS OF NONIONIZING ELECTROMAGNETIC RADIATION

by

Andrew Peter Sosnicky

September 1976

Thesis Advisor: O. M. Baycura

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER 9
4. TITLE (and Subtitle) 6 SOURCES AND BIOLOGICAL EFFECTS OF NONIONIZING ELECTROMAGNETIC RADIATION.		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis, September 1976
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 Andrew Peter Sosnicky, Lieutenant Commander, United States Navy		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School, Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 12 74 p.
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School, Monterey, California 93940		12. REPORT DATE 11 Sep[redacted]976
		13. NUMBER OF PAGES 74
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Biological Effects; Nonionizing Electromagnetic Radiation; Electromagnetic Radiation Hazards.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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(Page 1) S/N 0102-014-6601

Unclassified
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SOURCES AND BIOLOGICAL EFFECTS OF NONIONIZING ELECTROMAGNETIC RADIATION

by

Andrew Peter Sosnicky
Lieutenant Commander, United States Navy
B.S., United States Naval Academy, 1966

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL

September 1976

Author: Andrew P. Sosnicky

Approved by: O M Bayering
Thesis Advisor

Gary K Poock
Second Reader

Carl R Jones
Chairman, Department of Administrative Sciences

Jack R Borsting
Academic Dean

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This thesis is designed to provide an insight into the potential biological effects on humans resulting from exposure to nonionizing electromagnetic radiation emitted by communications and radar equipment. The spectrum considered extends from the extremely low frequency band, which may be employed for communicating with submerged submarines, through the microwave band, which is utilized for satellite communications and radars. The different views of the Soviet bloc and the Western nations are presented. A near term safety measure, the use of protective garments, is recommended while debate continues. The underlying intent of this thesis is to provide a compact document which can be used to introduce telecommunications managers and other interested personnel to the uses, characteristics, and possible hazards of this valuable portion of the electromagnetic spectrum.

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LIST OF ABBREVIATIONS

cm	centimeter
cw	continuous wave
E	electric field
EIRP	effective isotropic radiated power
ELF	extremely low frequency
EMP	electromagnetic pulse
EMR	electromagnetic radiation
ERP	effective radiated power
GHz	gigahertz
GW	gigawatt
H	magnetic field
HF	high frequency
Hz	Hertz
KHz	kilohertz
KV	kilovolt
KW	kilowatt
m	meter
MHz	megahertz
mJ	millijoule
MW	megawatt
mW	milliwatt
mWb	milliweber
PD	power density
PFD	power flux density (same as PD)
RF	radio frequency
SHF	super high frequency
UHF	ultra high frequency
VHF	very high frequency
VLF	very low frequency

I. INTRODUCTION

In February 1976, the Department of State confirmed that for at least the previous 15 years the Soviet Union has been beaming microwaves at the United States embassy in Moscow. Apparently the purpose is to jam the sophisticated electronic monitoring devices in the building. Several diplomats and their families have come forward, recalling that they experienced ailments such as eye tics, headaches, insomnia and irritability. Ambassador Stoessel, whose office reportedly received a large share of the exposure, is said to be suffering from anemia and eye hemorrhaging. (Ref. 42).

This incident has focused public attention on the possible hazards of microwave radiation. However, this is not a new area of concern. Before 1950, only a small segment of the population, primarily personnel involved in the operation of radar installations, was exposed to microwave radiation in significant amounts. The military, realizing the potential hazard, began to study the effects during the 1950's. In 1957 the Air Force established a tri-service ad hoc committee to study microwaves in order to establish safe exposure levels. Partly as a result of this study, the American National Standards Institute in 1966 decided upon a limit of 10 mW/cm^2 averaged over any 0.1 hour period. This standard is recognized as the occupational and industrial exposure guide. However, there is no specific limit for the exposure of the general population to microwave radiation. As an uncontrolled group, the population as a whole may not be able to withstand the same

degree of exposure as can a carefully screened small unit. (Ref. 20).

Since the passage of the Radiation Control for Health and Safety Act of 1968, Public Law 90-602, there has been an intense federally sponsored program to determine the biological effects of nonionizing electromagnetic radiation. Coordinated by the Office of Telecommunications Policy in the Executive Office of the President, this program directly affects and actively involves the United States Navy.

A comprehensive search of available literature has been conducted in order to produce a useful single document. During the course of this research, it became increasingly obvious that up to a certain point there is general agreement among the scientists of the world that thermal effects are associated with this form of radiation. However, upon entering the area of subtle non-thermal effects, two divergent schools of thought exist. Whatever conclusions which may be accepted are dependent upon which camp the reader chooses to join.

Individual chapters of this thesis will describe the phenomenon of nonionizing electromagnetic radiation, thermal and non-thermal effects, sources of emission, examples of situations experienced routinely by Navy personnel, and a description of current research programs of particular interest to telecommunications managers. Microwave radiation receives the greatest emphasis primarily because of the controversy concerning its alleged effects.

II. THE NATURE OF NONIONIZING RADIATION

The electromagnetic spectrum contributes greatly to the well being of mankind through the services provided by telecommunications, national defense, guidance and control of vehicles, public utilities, entertainment, and so forth. These services can cause either good or bad effects on man, depending on the power level, frequency, and how they are used. To ensure that the beneficial effects of electromagnetic energy greatly exceed any possible injurious effects, expertise is required of those trained to work with this type of radiation. The thresholds of amount of radiation must be carefully determined, as well as the frequencies where good effects may become bad. The degree of electromagnetic compatibility between a source of EMR and the receptor, that is, whether or not the dose will be harmful as the result of the emission of a given amount of energy emitted per unit of time, depends upon the following conditions: (1) the path loss due to the physical properties of the propagation medium; (2) the location of the receptor with respect to the emitter; (3) the impedance looking into the physical boundaries of the receptor; (4) the internal reactions of the receptor body in which energy is absorbed. (Ref. 35).

A. ENERGY LEVELS

While absorbtion of electromagnetic energy of any wavelength results in an increase of kinetic energy in the biological target, the photon energies of radio-frequency

radiations are extremely small. The energy content for microwaves is approximately 10^{-5} electron volts per photon, in contrast to X or gamma rays, the energy of which is rated as thousands or millions of electron volts per photon. In the presence of these X and gamma rays, the photon energy level is high enough to displace electrons from the parent atoms. This process of ionization creates additional electrical charges within the biological molocules.

Ionizing radiation causes little thermal effect. At densities that are low in terms of available kinetic energy, these rays are cool and deadly compared to the waves of similar density in the microwave and lower frequency range. On the other hand, according to the best evidence available, the most pronounced effects of microwaves are thermal in nature. Exposure to high density radio-frequency energy is hazardous and can result in excessive heating. The heat produced by microwave radiation is capable of adversely affecting living tissue if the organism cannot dissipate the heat as rapidly as it is produced.

B. POWER FLUX DENSITY

1. Definition

The concept of power flux density (PFD) is used to describe radiation intensity. This represents the energy which impinges on a perpendicularly located plane in one second. PFD is expressed in mW/cm^2. A discernible thermal effect develops when the dose exceeds 10-15 mW/cm^2.

2. Exposure Limits

To the casual observer, a glance at the present state of affairs in this area will provide a thoroughly confusing picture. On the one hand, microwave power densities up to 590 mW/cm^2 are used in clinics for routine diathermy treatment of many areas of the human body. There is research in progress involving the application of high power density levels for treatment of cancer and for quickly eliminating hypothermia after open heart surgery. However, on the other hand, there is a strong conflict over the relative safety levels of 10 mW/cm^2 as opposed to 0.01 mW/cm^2. (Ref. 15).

The 10 mW/cm^2 level is based on thermal equilibrium conditions for whole-body radiation. Heat dissipation capabilities are better for partial-body radiation, so higher levels of irradiation would therefore be acceptable. This is the case in medical diathermy where the levels may exceed 100 mW/cm^2. (Ref. 43).

Experimental microwave studies have demonstrated that a number of factors must be considered to determine exposure levels. They include:

a. the frequency of the generating equipment.

b. time length of exposure.

c. pulse repitition rate.

d. motion of air currents which influence the rate of loss of body heat.

e. environmental temperature.

f. body type and weight which affects surface area to mass ratio, thereby affecting absorbtion rates.

g. orientation of the body with respect to the source.

h. differences in sensitivity of organs and tissues.

i. effects of reflections. (Ref. 5).

Certainly an environmental exposure standard should not exceed the accepted occupational standard of 10 mW/cm^2 for periods greater than 0.1 hours or one mW/cm^2 during any 0.1 hour period, and perhaps it should even be lower. The occupational guide implies that the health conditions of the worker are known, that the actual exposure can be controlled, and the daily exposure is limited to approximately eight hours. None of these conditions apply when dealing with the uncontrolled exposure of the public at large. This suggests that any environmental standard should incorporate the flexibility necessary for upward or downward adjustment to take into account unique exposure situations. (Ref. 37).

Government agencies with authority to set standards include the Bureau of Radiation Health of the Department of Health, Education, and Welfare in product emission areas; the Occupational Safety and Health Administration of the Department of Labor; and the Environmental Protection Agency. In addition, states and the military can employ more restrictive standards for their own use.

As a point of interest, the Bureau of Radiation Health has decreed that microwave ovens may not leak more than one mW/cm^2 at the time of manufacture, and not more than five mW/cm^2 at any time during the life of the product.

The Navy's Bureau of Medicine and Surgery has established safe limits of exposure based on the power density of the radiated beam and the time of exposure. All areas in which the energy levels exceed these limits are considered to be hazardous. In the frequency range between 100 MHz and 100 GHz, the limits are:

a. For continuous exposure, the average power density is not to exceed 10 mW/cm^2 or equivalently, 36 J/cm^2 averaged hourly.

b. For intermittent exposure, the incident energy level is not to exceed 300 mJ/cm^2/30-second interval. (Ref. 23).

C. ELECTROMAGNETIC FIELDS

Electromagnetic fields in the spectrum between one megahertz and 100 gigahertz have special biological significance since they can readily be transmitted through, absorbed by, and reflected at biological tissue boundaries in varying degrees, depending on body size, tissue properties, and frequency. There is very little scattering by tissues in this frequency range. These characteristics can result in either medically beneficial effects or tissue damage, depending on the circumstances. The frequency range receiving the most attention in terms of biological interaction is in the microwave spectrum of 300 MHz to 10 GHz. This is because of the widespread use of high energy densities in highly populated areas and the better absorbtion characteristics in the tissues of man in this frequency range. (Ref. 15).

Most studies of hazards are based upon plane-wave

concepts in the near field of a microwave transmitter. This is done to achieve high field levels to determine damaging effects. However, a standing wave formed by two single plane waves of equal amplitude and the same polarization but opposite direction has zero time-averaged power density, yet both the electric and magnetic energy densities may be quadruple those of the original waves at specific locations. Such complications are not merely of academic importance. Measurements of near fields based on far field concepts must be regarded as simplistic and are often not quantitatively correct.

Within distances of roughly one wavelength from some sources, strong electromagnetic fields can exist with little or no time-averaged energy flux. However, there will be flow back and forth between the source and the surrounding space during a period of oscillation, similar to the flow between capacitors and inductors in a resonant electrical circuit.

A 26 meter parabolic antenna transmitting with a 500 kilowatt transmitter could theoretically emit a 26 meter diameter beam with an average power density of 150 mW/cm^2. The energy distribution of a typical Cassegrain parabolic microwave antenna is such that most of the energy is concentrated in the center nine to twelve meters and then drops off rapidly at the edges. This means that the power density in the center of the beam could be as much as 600 mW/cm^2. With microwave energy rebounding between the subreflector and the main reflector, hot spots exceeding 1000 mW/cm^2 can occur. This is equal to the level created inside a microwave oven. (Ref. 18).

D. WAVE PENETRATION

The electrical properties of tissues must be known in order to arrive at a complete understanding of the interaction of the organism and the radiation. When a body enters a field, the field is altered because the electrical properties of the body differ from those of the original propagating medium. The body surface reflects some of the incident energy, while some penetrates through the surface tissue.

The human body can be visualized as three layers with an equivalent thickness of 0.35 cm for the skin, 1.14 cm for the fat, and a semi-infinite layer for the muscles. As the frequency of the incident signal varies, so does the percentage of energy absorbed, as does the distribution within the different tissues. Microwaves penetrate to a depth which is equal to approximately one-tenth of the wavelength. Therefore, millimeter waves are absorbed in the skin, while decimeter waves penetrate to a depth of 10-15 centimeters. Deepest penetration occurs at 0.9 GHz, whereas minimum penetration occurs above nine GHz. (Ref. 18).

A major factor which distinguishes the biological response to microwave radiation as opposed to radiation by infrared and ultraviolet energies is that the latter are absorbed or scattered near the surface of a target. Unscattered microwave energy penetrates much more deeply. For example, if a one gigahertz signal is incident on the head of a human being, a significant portion of the energy will penetrate the skull and be captured by the tissues of the brain. One of the hazards of microwave energy is that the warning sensations of warmth so readily produced by infrared energy through stimulation of surface receptors may not occur during exposure to even fairly high density

microwave energy until after thermal damage has resulted. (Ref. 17).

This hazard has been demonstrated in an analogous situation. When a .75 inch slab of butter was placed upon a cut of beef and then exposed to 10 centimeter wavelength radiation, the butter melted first at the interface, rather than at the outer level of the butter as one might expect. (Ref. 23).

E. ENERGY ABSORBTION

A rough rule of thumb for estimating absorbtion of radio-frequency energy when the biological target is large with respect to the wavelength of the incident signal is that approximately half the energy is absorbed and the remainder is scattered. When the target is much smaller than the incident signal's wavelength, the target becomes electrically transparent and little or no energy is absorbed. When target size and wavelength are about equal, an extremely complex scattering function occurs, and either very little or a great deal of energy is absorbed. Electrical resonance may occur, permitting maximum absorbtion which may even exceed the nominal amount of energy that is incident on the target. (Ref. 17).

Studies have proven that the amount of energy absorbed is partially dependent upon the shape of the target. In one case, when a human form was placed in a one volt/meter field, the energy absorbed was more than three orders of magnitude higher than that of an equivalent volume sphere and two orders of magnitude greater than that for an equivalent volume ellipsoid. The high absorbtion in the narrow cross-sections of the body is due to the

constrictions of the induced current along the length of the body, thereby increasing the current density and electric fields in those areas. The arms are less affected because they are parallel to the trunk which shunts most of the induced currents. Peak absorbtion occurs in regions where the flow of the circulating eddy currents are forced into the smaller cross-sectional areas or are diverted by severe angular changes of the tissue. Typically, these would be areas such as the knees, ankles or neck. (Ref. 10).

The absorbtion or heating patterns induced by radiation are nonuniform and are dependent on the dielectric properties of the tissue, primarily the dielectric constant, a measure of the polarizability of the medium, and the conductivity, a measure of the ease in which electrically charged particles move through the medium. These properties are also functions of frequency. Since water has a relatively high dielectric constant and conductivity, the absorbtion is high and the depth of penetration is low in tissues of high water content such as muscle, brain tissue, internal organs and skin.

Under otherwise similar conditions, the following order of susceptibility to SHF fields has been established: lens of the eye, liver, intestines, and testes. Absorbtion is an order of magnitude lower in tissues of low water content, such as fat and bone. Reflections between interfaces separating tissues of high and low water content can produce severe standing waves accompanied by hot spots that can be maximum in either tissue, regardless of dielectric constant or conductivity. (Ref. 15).

III. THERMAL AND NON-THERMAL EFFECTS

Effects are usually designated as thermal if they result from heating the tissue, and if they can be duplicated by conventional means. Non-thermal effects are those which result from the interaction of the electromagnetic field with the biological material and cannot be reproduced by conventional heating techniques.

A. THERMAL EFFECTS

Microwave heating of biological materials involves two electrophysical properties of water. First, the water molecule is polarized, carrying a differing charge over its surface. The nuclei of water precess around the direction of the applied field just like a gyroscope that precesses around the earth's directional field. Each atom has its own natural resonant precession frequency when acted upon by an external field. The result is an electrical dipole, a molecule which reorients itself whenever an external electrical field is impressed on it. Water's second property is a high molecular viscosity, which prevents complete orientation and reorientation in a rapidly oscillating electrical field. If there were no frictional forces, all the energy associated with the oscillation at resonance would be alternately stored and returned by the atom to the field. However, friction does exist and heating will always occur to varying degrees.

In areas where little blood circulates, the temperature

may rise more rapidly than in other parts of the body since there is little means for heat exchange. Therefore, tissue damage is more likely to occur in those areas where a greater rise in temperature occurs. The lens of the eye is an obvious example. The transparent lens appears to be easily damaged by intense radiation energy, whether ionizing, infrared or microwave. Damaged cells lose their transparency, forming opaque areas commonly known as cataracts.

B. NON-THERMAL EFFECTS

There are numerous reports of nausea resulting in personnel exposed to microwaves in the nine to twelve gigahertz range. Also, certain people perceive an auditory response in the form of a buzzing sound when exposed to frequencies between 0.2 and 3.0 GHz in a pulse-modulated mode.

The nervous system has also been shown to be highly susceptible to the effects of microwaves. Under identical irradiation of the head, trunk, and extremities of an animal, the greatest changes are observed in the head. (Ref. 16).

1. Central Nervous System

The literature is abundant with reports on the effects of electromagnetic fields on the central nervous system and on peripheral nervous systems of both man and animals. A large number of papers indicate that these effects can take place at relatively low incident field levels, while others show effects only with high incident

field levels. Additionally, there is debate about whether the observed effects are thermal or non-thermal in nature.

2. Pearl Chain Formation

Another interaction mechanism is the field-force effect. Applying the principle that a system will tend to minimize its potential energy, it has been possible to observe effects known as pearl-chain formation and particle orientation. Particles, when suspended in a fluid whose dielectric constant is different from that of the particle, become electrically polarized when they are subjected to a high frequency alternating field, creating electrical charges on the particle's boundaries. In effect, an electrical dipole is formed which then is influenced by the electric field so as to align with the field. When the distance between particles is small and the field strength is large, characteristic chains will form. These "pearl-chains" form readily in the blood, analogous to the alignment of iron filings in a magnetic field. These orientation effects occur only at power levels of approximately 500 mW/cm^2 and above, which are much higher than the accepted safe level of exposure. The detrimental effect of this phenomenon, if any, is not precisely known. (Ref. 26).

3. Aural Sensation

Humans can "hear" microwave energy. The origin and a clear understanding of the microwave hearing phenomena is important since the present safety standard of 10 mW/cm^2 is

five orders of magnitude greater than the threshold level for producing an audible sensation by a single short pulse.

The most likely cause of this sound appears to be conversion of electromagnetic energy to acoustic energy through thermal expansion in the tissues within the head. A prerequisite for interaction with the material is that the dielectric constant or conductivity be sufficiently high and the frequency proper to allow for a penetration of energy and loss over an appreciable fraction of the volume when the object is exposed to a microwave pulse. Certain tissues in the human head meet the requirements.

The fact that the sounds are produced by pulse energy levels so low that they only raise the tissue temperature 5×10^{-6} °C points out the extreme care which must be exercised when trying to classify an effect as thermal or non-thermal based simply on the level of temperature increase. (Ref. 12).

IV. SOVIET STUDY OF NON-THERMAL EFFECTS

Soviet findings differ markedly from those of Western authorities. Russian scientists have emphasized the interaction of EMR with the central nervous system and related areas, while the Americans and others have concentrated on the thermal effects on physiology. At the present time in the USSR, extensive clinical material has been accumulated on radio and radar station operators. Initial complaints from different individuals have been reported at various periods of time after irradiation commenced, ranging from several months to several years.

A. SUBJECTIVE EFFECTS ON THE CENTRAL NERVOUS SYSTEM

A large number of Soviet bloc studies have consistently documented subjective complaints which are usually referred to as evidence of the direct or indirect effect of microwaves on the central nervous system. These responses have been noted for a wide range of frequencies (30-300,000 MHz) at both thermogenic (greater than 10 mW/cm^2) and non-thermogenic intensities. General complaints include:

1. pain in the head and eyes
2. abnormal secretion of tears
3. weakness and weariness
4. dizziness
5. depression
6. antisocial tendencies and general irritability
7. hypochondria

8. sense of fear
9. impairment of memory and general mental function
10. inability to make decisions
11. inhibition of sex drive in males
12. loss of hair
13. chest pain and heart palpitation
14. indigestion, epigastric pain, and loss of appetite
15. trembling of eyelids, tongue, and fingers
16. asthma
17. brittle fingernails

In general, many of these studies postulated that the responses were highly dependent upon length and degree of exposure, and that most subjective symptoms were reversible. (Ref. 6).

B. SOVIET CLASSIFICATION OF GENERAL CLINICAL SYNDROMES OF EXPOSURE TO MICROWAVE RADIATION

1. Asthenic Syndrome

This is characterized by fatigue, depression, and a number of other changes. It is not marked by any severe episodes such as fainting or gross changes in pulse rate or blood pressure, and the subject responds to outpatient treatment.

2. Autonomic Dystonia

This stage is characterized by instability of the pulse and blood pressure, EKG changes and fainting spells.

Severe episodes may occur and the subject requires hospitalization of unspecified nature and duration.

3. Diencephalic Syndrome

This stage is characterized by hypersomnia, hypothalamo-pituitary weakness, and inhibition of sexual and digestive reflexes. Panov claims that these changes are not always reversible and that subjects require hospitalization. (Ref. 31).

C. STUDIES AT EXTREMELY LOW FREQUENCIES

The Russians have been very active in recent years studying the effects of 50 Hz electromagnetic fields at strengths between 15 and 420 mWb/m^2. The average field to which the subjects were exposed was generated by 14 to 18 KV and 115 to 125 microampere sources at Volga power stations. Most of the observed industrial workers exhibited slight departures from the normal health indices. Most frequently they indicated changes in the nervous system, mainly in autonomic functions. Incidents of headaches, increased fatigue, physical weakness and perspiration were also reported. One third of the men in their fourth decade complained of diminished sexual vigor after eight to ten months at the power station. (Ref. 28).

D. SOVIET THERAPY

According to the Soviets, the most successful form of

therapy consists of termination of contact with SHF electromagnetic fields. Patients should receive nutritious food as far as caloric value and vitamins are concerned. Various forms of psychotherapy are also important in the complete theraputic regimen. Among the patients there have been individuals frightened by the nature of their symptoms and who exaggerated their effects. In such cases it has been beneficial to try to disspell their ungrounded fears and impart a belief in a favorable outcome. (Ref. 16).

E. WESTERN OPINION OF SOVIET FINDINGS

Disparities between Soviet bloc and Western standards reflect a basic difference in experimental approach to related biological research. The Soviet Union centers on changes exhibited by the functional state of animal subjects, that is, behavioral and psychological changes. Concepts developed to explain many of these effects, to a large part determined from information theory, have not been substantiated sufficiently to gain widespread acceptance in the West. Conversely, Western scientists tend to rely on observations of psysiological and biochemical changes. Considerable controversy exists at present over reconciliation of these differences. (Ref. 36).

Generally, the syndromes and organ responses described in Soviet literature have not been observed by Western physicians, at least not at the PFD at which they are reported to occur. Western medicine, believing in the ability of microwave energy to produce selective heating, tends to view the potential damage to the lens of the eye and possibly the testes as the critical points, based on their relative inability to tolerate heat. The assumption that microwaves do not act directly on tissue structures,

but only through the heat which they develop as they are absorbed, is apparently supported by biological principles. These principles pertain to the action of electrical fields on molecules and membranes: that is, membranes are virtually transparent to microwaves, and large molecules turn too slowly and are too massive to respond to microwave fields as far as is known at this time. Thus, the Western belief is based on two ideas: (a) the available basic knowledge from the action of fields on biological components; and (b) physiological considerations about man's thermal regulation, namely, his ability to get rid of internally developed heat, whether by eating food and burning it up while working or by absorbing microwaves. (Ref. 33).

An often disappointing facet of the Soviet and East European literature on the subject of clinical manifestations of microwave exposure is the lack of pertinent data presented on the circumstances of irradiation: frequency, effective area, orientation of the body with respect to the source, pulse and modulation characteristics of the waveform, exposure duration, and so forth. Despite these omissions, there have been an impressive number of clinical and hygenic surveys involving literally thousands of people over the past 20 or more years, and their effort has been significant enough to merit Western consideration. (Ref. 31). Since their safe level of exposure is based on neurological and behavioral effects, their findings should not be arbitrarily rejected until such time that there is sufficient proof that these effects are not detrimental to the health of mankind.

The Soviets define a substantially lower maximum permissible dose value for human exposure to microwave radiation (0.1 mW/cm^2 versus 10 mW/cm^2 in the United

States). This appears to be based upon extensive findings of responses to low field intensities. At this time, however, it is probably impossible to make a final judgment on which dosage is more valid. Only in the realm of human endocrine, visual, and skin perceptor responses to microwaves is there any substantial agreement.

V. SIGNIFICANT SOURCES OF RADIATION

The nonionizing radiation environment consists of electromagnetic radiation which exists over a wide range of frequency (0-300 GHz). Power density at any frequency is dependent upon the sources in the general area and the geometry which exists relative to the source and that particular point in the environment. A high power source can be defined as one which is capable of producing an arbitrarily chosen power density of 0.01 mW/cm^2 or more, at a distance from the antenna where free access would ordinarily be possible, with inadvertant exposure of individuals, unless restrictions were intentionally imposed. With this definition, it is possible to differentiate between high power sources and potentially hazardous sources which are those capable of producing power densities above this threshold, on the order of 10 mW/cm^2, but only at distances relatively close to a system antenna where inadvertant exposure of an individual is highly unlikely. (Ref. 14).

A. COMMUNICATIONS EQUIPMENT

1. Broadcast Media

Analyses and measurements have produced information relating to radiation characteristics, potential hazard

evaluations, and environmental radiation levels associated with high power source categories, which include satellite communication earth terminals, military and civilian radars, and broadcast transmitters (UHF and VHF television, and AM or FM radio). These results when combined with other factors such as number of sources in each category, relative numbers of persons possibly exposed, and general system operating characteristics, lead to the conclusion that broadcast transmitters constitute the most environmentally significant source category. The levels of exposure associated with them exhibit a wide dynamic range but generally are not considered to represent a hazard. Specialized circumstances, however, are still being investigated to determine the real extent of possible hazards. (Ref. 14).

As of January 1975 (Ref. 37) the number of radio and television broadcasting stations on the air in the United States was:

513	commercial VHF television
198	commercial UHF television
95	non-commercial VHF television
147	non-commercial UHF television
4434	AM radio
2648	commercial FM
725	non-commercial FM
8760	total broadcasting stations

During 1973 a study was conducted in the Washington, D.C. area to determine the level of HF spectral activity on a typical day. It was found that signal activity was due primarily to commercial radio and television stations, with maximum exposure occurring between the hours of 2000 and 2400. Activity was predominantly within the 2-18 MHz portion of the band with exposure values falling by approximately 30 dB or more above 22 MHz. Primary exposure

in any band appeared to be a function of the few strongest signals, with the remaining signals contributing essentially nothing in terms of total spectral power. None of the signals created a power density greater than 1 mW/cm^2. (Ref. 40).

Approximations of ground level field intensities from a UHF television broadcast complex have been made for potential hazard analysis. A transmitter site in the Washington, D.C. area was chosen where stations WDCA (channel 20) and WETA (channel 26) are colocated on the same tower. The combined ERP, including both visual and aural carriers, was approximately 5.6 MW, one of the most powerful UHF outlets in the nation.

As a result of this study, under no circumstances can field intensities greater than 0.028 mW/cm^2 be envisioned at ground level, this occurring directly beneath the tower. Since the case considered represented a combined ERP greater than the maximum possible authorized power for a single UHF station (5 MW), it is inconceivable that any station could produce fields greater than those calculated. (Ref. 38).

In another study, power density calculations were performed using the standard free space equations and inclusion of possible reflections which would enhance the field intensity. It was determined that the maximum computed power density existed at a roof top installation of KAFG-FM in Oklahoma City, Oklahoma, with a value of 21.4 mW/cm^2 at a frequency of 102.7 MHz. Table 1 is a statistical summary of FM station data. (Ref. 37).

Because personnel routinely work on energized broadcast towers, the currents and the fields on such towers should be investigated further to determine actual exposure and absorbed dose rate. Careful consideration should be given to work on towers or buildings immediately adjacent to high power broadcast stations, especially UHF television.

2. <u>Satellite Communications</u>

In order to determine potential relative importance to the environment, the Electromagnetic Compatibility Analysis Center at Annapolis ranked the most powerful microwave sources on the basis of EIRP. Effective isotropic radiated power is defined as the hypothetical total power which a non-isotropic source of electromagnetic radiation would be required to radiate as a point source such that the power radiated per unit solid angle would be the same as that actually radiated. It is calculated by multiplying the power radiated by the antenna gain. This included both non-pulsed (cw) systems and pulsed (radar) systems. Of the 20 most powerful systems identified, all were satellite communication earth terminals. They are listed in Table 2. Table 3 depicts other characteristics of selected satellite systems.

These earth terminals, as a general class, have the greatest potential for creating hazardous situations because significant power densities may exist at greater distances from the antenna than would be possible from other types of radiating systems. They irradiate a particular region of the environment for long periods of time while tracking satellites in various orbits, moving very little in direction or elevation as they do so. As systems are required to provide ever higher data transmission rates at increasing distances, transmitter power and antenna diameter

increase. It is this combination of output and size that is responsible for producing a region of significant power density which may extend over very large distances.

An important characteristic of high power sources, in addition to the maximum power density which can be generated, is the extent of the near field, the distance from the antenna over which the power density can be a maximum before it begins to decrease with distance. This parameter and the maximum power density in the near field determine the value of the on-axis power density at any distance from the antenna. The extent of the near field, R_1, can be determined by the following equation:

$$R_1 = D^2/5.66wl$$

where wl is the wavelength of the transmitted radiation and is expressed in the same units as the antenna diameter, D.

The intermediate field region is a transition region in which the power density decreases inversely with distance. The far field of the antenna is the region in which the beam diverges and the power density decreases inversely as the square of the distance from the antenna.

Many factors must be considered when operating any ground station. Many satellite communication systems cannot operate at elevation angles less than a specified angle relative to the horizontal. The knowledge of that angle and other system and site characteristics, such as terrain features, antenna height above ground, population distribution, location and height of structures, and sidelobe radiation characteristics of the antenna, will realistically determine the possibility of exposure of persons within a radius for which the power density exceeds the acceptable threshold level.

In general, if operated in accordance with prescribed operating procedures, satellite communications systems should not constitute a thermal effects hazard. The possibility of exposure of persons should be extremely small because on-axis radiation is directed upward, and low angles of elevation are mechanically prevented. Aircraft flying through the beam would normally be well out of the dangerous near field. (Ref. 7).

B. RADAR

The characteristic of primary interest in radar system radiation measurements is time-averaged power density, not peak power density. The radiation is pulsed, and for most systems, the pulse width and repitition rate are such that the average transmitter power density created at any point is roughly two to four orders of magnitude less than the peak value. In addition, many radars rotate, further reducing the time-averaged power density at a particular location.

Of all radars operating in the United States, the majority operate in the scanning mode and produce rotational time-average power densities less than 0.01 mW/cm^2 at ground level in the antenna far-field region. Tracking radars, being non-rotational, are generally capable of producing hazardous levels at much greater distances from the antennas. However, the most powerful of these are usually located in areas where the possibility for exposure of large numbers of persons would be minimal. They are operated in such a way that would minimize exposure in free access areas and practically eliminate inadvertant exposure.

In order to determine the potential exposure of individuals when in the vicinity of aircraft radar units when the aircraft were on the ground, the Environmental Protection Agency monitored four typical radars used by commercial aircraft. The survey determined that the radar beams from navigational and weather units produced a power density of 10 mW/cm^2 at a distance of eight to eighteen feet from the antenna. It should be noted that the radar was not rotating during the test, which would not normally be the case.

On the basis of this study, the following facts were determined:

1. Typical maximum power for aircraft radars lies in the range of 20 to 100 KW peak, 20 to 120 W average.
2. Antenna gains are normally in the range of 25 to 30 dB.
3. Peak effective radiated power (ERP) is in the range of 6 MW to 100 MW, 6 KW to 120 KW average.
4. No radiation levels in excess of 0.2 mW/cm^2 existed in the aircraft cockpits.
5. In general, the radar beams of commercial aircraft are above six feet in height from the ground.
6. Reflections from nearby objects cause irregularities in the field structure. (Ref. 39).

Satellite communication and tracking radar antennas produce very well collimated beams, and off-axis radiation levels are greatly reduced relative to main beam radiation levels. The ratio of off-axis power density to on-axis power density at any far-field location is generally less than 0.01 at angles greater than five degrees relative to the antenna axis for systems having small diameter antennas. This ratio decreases as off-axis angle increases, and the

angle at which a given ratio may exist decreases as antenna diameter increases and wavelength decreases. (Ref. 14).

C. COMPARISON OF SELECTED SYSTEMS

As shown in Table 3, for those systems having antenna diameters which vary from 15 feet to 210 feet, the near field increases from approximately 100 meters to almost 6000 meters. With the exception of the Intelsat system, the on-axis near field power densities are significant relative to 10 mW/cm^2.

The results of studies of other common sources of microwave radiation have been summarized in Table 4. (Ref. 13). Although the number of systems studied in each category was relatively small, the statistics are useful to point out the relative relationships. It should be noted that the average power densities shown for radars do not include a reduction due to antenna rotation.

For all categories except the UHF television stations, there are systems capable of producing hazardous exposure levels. For most systems, even when considering a power density of only one mW/cm^2, it is likely that exposure to the general population could easily be prevented by means of restricting access to the areas involved.

Most source characteristics needed to assess an exposure situation are available. However, such factors as biological effects are difficult to incorporate into calculations, and may be responsible for significant differences between measured and calculated results.

TABLE 1

Statistical Summary of FM Data

Power Density Range (mW/cm^2)	Number of Stations	Percentage of the 86 $\geq 1\ mW/cm^2$
1.0 - 1.99	37	43.1
2.0 - 2.99	21	24.4
3.0 - 3.99	7	8.1
4.0 - 4.99	8	9.3
5.0 - 5.99	7	8.1
6.0 - 6.99	0	0
7.0 - 7.99	0	0
8.0 - 8.99	2	2.3
9.0 - 9. 99	1	1.2
10.0 - 10.99	1	1.2
-	-	-
21.0 - 21.99	2	2.3

There are 86 FM stations which produce a power density greater than 1 mW/cm^2.

TABLE 2

Ranking of Sources by Average EIRP (GW)

Rank	Location	MHz	EIRP
1	Westford, MA	7748	31.6
2	Lakehurst, NJ	8004	20.0
3	Roberts, CA	7985	20.0
4	Rosman, NC	5925	11.3
5	Paumalu, HI	5925	7.9
6	Jamesburg, CA	5925	7.9
7	Etam, WV	5925	7.9
8	Brewster, WA	5925	7.9
9	Andover, ME	5925	7.9
10	Bartlett, AK	5925	7.9
11	Archer City, TX	217	6.4
12	Mojave Desert, CA	5985	6.4
13	Point Loma, CA	7997	5.0
14	Helamano, HI	7990	5.0
15	Fort Monmouth, NJ	7990	5.0
16	Brandywine, MD	7986	5.0
17	Camp Parks, CA	7990	5.0
18	Wildwood, AK	7986	5.0
19	Floyd Test Annex, NY	7986	5.0
20	Elgin, IL	8004	5.0

TABLE 3

Anticipated Characteristics of Selected Satellite Systems

System	Antenna Diameter (ft)	wl (cm)	EIRP (GW)	R_1 (m)	Max PD (mW/cm^2)	Meters from Antenna for PD $\geq$ 10 mW/cm^2
AN/TSC-54	18	3.7	0.651	144	50.8	458
AN/MSC-46	40	3.7	2.68	710	8.56	-
AN/MSC-60	60	3.7	4.82	1600	3.04	-
AN/FSC-9	60	3.7	12.0	1600	7.61	-
Intelsat	97	4.8	4.68	3220	0.73	-
Goldstone Venus	85	12.6	54.0	943	97.3	4160
Goldstone Mars	210	12.6	348	5760	16.8	9680

Note: Goldstones are not satellites. They are systems used to communicate with space vehicles on planetary exploration missions.

TABLE 4

Characteristics of Microwave Sources by Category

	Maximum Power Density (mW/cm^2)	Near Field Distance (m)	Distance (m) to 10 mW/cm^2
Satellite Communication Earth Terminals	3 to 97	100 to 6000	-
Radars			
Search and Tracking	11.5 to 800	6.5 to 22	9.7 to 111
Air Traffic Control	2 to 15.5	18.6 to 31.2	out to 48.3
Aircraft Weather	29 to 82	0.5 to 1.7	2 to 5
UHF-TV	0.03 to 0.25	-	-

VI. UNITED STATES NAVY CASES

The Navy is conducting on-going studies to determine the applicability of the maximum permissible exposure level over the entire spectrum, the existence of possible specific hazardous frequencies, threshold power levels for particular damage, cumulative effects, and other topics of interest. The Electromagnetic Survey Group of the Naval Ship Engineering Center is responsible for determining hazardous areas and ensuring that the possibility of biological injury is minimized.

This group has made measurements aboard ships of all types. The surveys are conducted on the lead ship of each new class, as well as whenever a significant modification occurs to an electronics installation. Through the use of computers it is now possible for them to predict during the early stages of a ship's design the presence and degree of hazard to be anticipated. Awareness of potential hazards has led to the design of many safety features in modern equipment. For example, interlocks have been incorporated to prevent accidental ground operation of radar if there is any weight on the wheels of the F-14 fighter aircraft. (Ref. 23).

A. SHIPBOARD

The Navy has a unique operational problem in that shipboard personnel must necessarily work within fixed distances from RF and microwave-radiating antennas. In

addition to direct radiation hazards, there exists the danger from premature activation of electroexplosive devices in ordnance items, damage to radio receiver crystals, and ignition of aviation fuel vapors. A human can be endangered whenever metallic objects are handled in the vicinity of high-powered transmitters. This could occur while plane crews are handling aircraft on the deck of a carrier or when crane operators are lifting cargo on replenishment ships. The most common example of a personnel hazard in these cases is the minor burning of the skin occurring when contact is made with the conductor containing induced RF current. Measurements have been made in excess of one ampere and 300 volts when an aircraft was parked next to a transmitter whip antenna radiating an estimated 1400 watts.

Since the ship itself is a very complicated radiating structure down to the waterline, shipboard measurements are extremely difficult, if not impossible, to make precisely. Reflective surfaces and secondary radiators exist in moving booms, rigging, and other rotating antennas. In the case of aircraft carriers, even the placement and movement of aircraft on the flight deck affect the power density levels. Qualified shipboard personnel can routinely conduct power density surveys using thermistor type meters, such as the AN/USM-177 series. Techniques for the general operation of these instruments are contained in the Technical Manual for Radio Frequency Radiation Hazards (NAVSHIPS 0900-005-8000).

1. Aircraft Carriers

Actual surveys aboard aircraft carriers have revealed the existence of power density levels in excess of 100 mW/cm^2. In some cases the limiting radiation hazard

distance is greater than the overall length of even the largest ships. A number of suggestions have been made to modify the presently accepted exposure levels to alleviate this dilemma. If the levels are set too liberally, however, the danger to personnel is obvious. On the other hand, if they are set too conservatively, undue restrictions might be imposed on the operational capability of the fleet.

An examination of the field strengths on the flight deck of the USS Forrestal was conducted several years ago. The only significant hazard in terms of acceptable radiation levels was caused by the AN/APS-20E airborne radar while the aircraft was on the flight deck radiating with a stationary antenna. The values were 14 mW/cm^2 at 25 feet and 70 mW/cm^2 at 18 feet. However, standard operating procedure for this radar called for the use of a dummy load until the plane was airborne and scanning of the antenna when radiating. The test conditions were artificial and field strengths of that magnitude would not have been encountered during normal operation unless there was an improbable combination of intent and deviation from standards. All other high-powered microwave antennas were well above populated areas, so there was little possibility of exposure to radiation of significant strength from those sources. There is no reason for carrier or maintenance personnel to fear exposure if standard operating procedures are adhered to and personnel remain outside minimum safe distances from operating radar. (Ref. 1).

2. Missile System Radar

A fairly recent addition to the fleet is the radar associated with the basic point defense missile system. During an inspection of one such installation, frequency

selective measurements detected a power density level of 20 mW/cm^2 within 19 feet of the antenna. A hazard threshold distance of 27 feet was determined, but there were no proper provisions tc prevent personnel exposure, other than a warning sign on the mount relating to direct visual examination of microwave sources. There was nothing to prevent the radar from being aimed across the flight deck when radiating. (Ref. 27).

3. Communications Equipment

Present day long distance communications from ships require the use of high-power transmitters operating in the 2-30 MHz range. An inherent characteristic of their antennas is that they use the ship's structure as part of the radiating element. RF currents flow over the entire metallic surface of the ship, contibuting substantially to the performance of the antenna.

Another normal consequence of antenna radiation is the coupling of RF energy into metallic objects. The amount of energy intercepted or voltage developed depends on the length of the object, transmitter power, frequency, distance to the radiating antenna, and the presence of any intervening metal structures.

Any metallic structure or device is a potential RF burn hazard when its length approximates one-fourth the electrical wavelength of the frequency of radiation transmitted from a nearby HF antenna. This resonant length is about 123 feet at two MHz and eight feet at 30 MHz. As a ship changes transmitter frequencies to meet varying circuit requirements, various topside items such as ladders, masts, and booms become resonant in turn. It should be noted that

higher frequency systems such as VHF and UHF transmitters do not contribute to the RF burn problem.

Individuals touching metal objects which have RF induced voltages below 100 volts experience no sensation. Between 100 and 140 volts, tingling is felt. Above 140 volts, the result can be burns of varying degree. These high frequency currents tend to flow on the surface of the body, rather than through internal organs such as the heart. Since the body is not a good conductor, the energy is dissipated in the area of contact, resulting in heat and a possible burn. Therefore, electrocution, as commonly understood, is not associated with RF currents. (Ref. 32).

4. Elimination of Hazards

While there is no simple method to completely eliminate RF burn hazards aboard ship, there are ways to reduce them. The techniques used to either eliminate or reduce radiation to accepted levels include:

a. mounting transmitting antennas above the highest manned level.

b. utilizing emission controls such as cam cutouts to prevent antennas from radiating within the profile of the ship as seen by the antenna beam.

c. limiting access to certain spaces while equipment is activated.

d. using area shielding to permit occupancy of otherwise hazardous weather decks.

Specific techniques operational communications personnel can employ include the following:

a. Cease using the particular antenna causing the problem. Experience has shown that in most cases the problem can be traced to one antenna specifically.

b. Avoid the use of frequency/antenna combinations which generate the problem. Tests have indicated that there are segments of a band which cause problems, while the rest of the band is perfectly safe on that antenna.

c. Lower the output power of the offending transmitter. A reduction from one kilowatt to 500 watts will usually reduce the burn potential with relatively little effect on communications, unless the circuit was marginal to begin with. This is particularly true above six MHz, where sky wave propagation predominates, and therefore frequency and antenna selection have more influence on circuit quality than transmitter power does.

d. Use UHF links to relay message traffic to nearby ships for further transmission during underway replenishments.

e. Install insulators between the hook and the rigging on booms.

f. Use non-metallic substitutes for lifelines, ladders, flag bags and so forth as replacements become available. (Ref. 32).

B. VLF

The sailor and the pilot for many years have relied on low frequency radio services. There are several reasons for the strong interest in the low frequency bands below 300 KHz. First, there is a need for extremely high accuracy in frequency and time measurement. Because VLF and LF transmissions avoid the significant, although small, errors that occur in the higher frequency ranges, they are well suited for this job. Second, for security reasons, everything possible must be done to keep communications networks from breaking down as a result of ionospheric disturbances. Low frequency transmissions are not affected

by this shortcoming. Finally, far better communications can be maintained with submerged submarines by means of VLF and ELF transmissions than by any other method available at this time.

As the use of high power, low frequency band stations proliferates, the question of the danger of radiation to the men who operate and maintain the stations has been raised, particularly as it pertains to those workers who have to periodically climb the towers.

Evaluation of the physiological and behavioral effects of VLF energy requires measurement of the fields which produce those effects, from threshold level to the maximum strength routinely encountered. The strength of the "near" field of a dipole antenna - the field within five wavelengths - is the sum of the strength of the radiation field (the electromagnetic field which breaks away from the antenna and travels outward into space as electromagnetic waves) and the strength of the induction field (the electromagnetic field which acts as though it were permanently associated with the antenna). At the Navy's Cutler, Maine transmitting site, the frequency of 14.7 KHz is typical, with a corresponding wavelength of about 12 miles. Within the 60 mile "near" field the strength of the radiation field is negligible compared to that of the induction field. Within one wavelength the electrical component of the induction field is dominant over the magnetic component.

A test was conducted to determine effects when 1100 KW of power was being radiated. At a point 470 feet up the antenna, a mild tingling electric sensation was produced when bare metal was touched. An aluminum hardhat drew a small spark when touched to the bare metal at the same height. The ac field measured 12 inches outside the tower

framework was 30,000 volts/meter.

At the top of the 980-foot tower, the ac field was found to be 989,000 volts/meter. All metal contact produced a strong electric shock when touched, comparable to that received from a 110 volt ac source. In addition there was a large static field caused by atmospheric electricity undoubtedly present outside the framework near the top.

It is likely that there was also an enormous concentration of air ions. Each tower, acting as a huge corona point in the static field of the atmosphere, has a discharge current greater than that observed from ordinary lightning rods (.0001 ampere). In addition, the very high alternating voltages appearing across the antenna insulators produce a corona discharge of large magnitude. The shock sensation reported to occur downwind from the radiating antenna is *probably* caused by this air ionization. (Ref. 8).

C. PROJECT SANGUINE/SEAFARER

1. Background

Project Sanguine/Seafarer is the Navy's ELF submarine communications system. The project is currently in the research and development stage.

The Sanguine signal (45 Hz) is induced when current is caused to flow from a large cable antenna through an earth return loop. The current flows into the earth at one terminal ground and returns through the earth to the other terminal ground. Magnetic flux density induced by the 150

ampere transmission approaches 0.15 gauss near the antenna cable and diminishes to 0.01 gauss ten meters from the cable. The electric field is about 0.06 volts/meter near the cable, and 0.04 volts/meter at 100 meters from the antenna.

As a comparison, an incandescent light bulb measures 2 volts/meter; a color television, 30 volts/meter; a phonograph, 90 volts/meter; and an electric blanket, 250 volts/meter. The magnetic fields of the system compare favorably to a color television's value of one to five gauss; the five to ten gauss of an electric shaver; and a hair dryer's ten to twenty-five gauss.

2. Results of Studies

In the formation of any research program, there are usually clear causal relationships which provide a basis for further investigations. This was not the case when the Navy and other groups began the ELF biological research program. To compound the problem, the Sanguine program faces the possibility of having to prove a negative hypothesis, that is, there really are no harmful effects on living systems.

The Navy and independent research teams have conducted over 35 separate studies in the last seven years. To date, results show no significant adverse effects on humans, animals, plants, or microorganisms at electromagnetic field levels to be used for an operational ELF system.

ELF radiation, even at levels many times higher than those expected from the Sanguine system, contains too little energy to produce measurable heating effects. The possibility of genetic effects is even more remote.

Furthermore, there have been no proven biological effects from the 60 Hz electric and magnetic fields produced in today's environment by commercial electric power systems. These fields are similar in both frequency and energy levels to those a Sanguine system would produce.

The types of studies which have been or will be conducted as part of the Sanguine program include: genetics, fertility, physiology, growth and development, biochemistry, biorhythms, behavior, orientation, and population surveys. They have been done with plants, low order animal species, primates, and man. (Ref. 2). There have been no indications of genetic, fertility, growth, or other physiological effects. (There is, however, some indication of behavioral and physiological response to low energy fields at frequencies below those of the Sanguine project.)

The effect of extremely low frequency electric fields upon plant growth was studied in a controlled environment chamber using snap beans as the test species. A 45 Hz horizontal field of ten volts/meter was applied to containers of soil or nutrient solution in which the plants were growing. With the soil from the Clam Lake, Wisconsin test site for the Project Sanguine antenna packed at the normal bulk density, only a small current passed through the root zone and no influence of the field was detected. It was concluded that whatever electrical effects may exist, they will probably be insignificant in an actual installation if the field strength is no more than the 0.07 volts/meter as proposed. (Ref. 30).

A survey was performed at the Sanguine North Carolina test facility in 1970 to assess whether operation of the facility had any effect on adjacent forest ecosystems. The facility consisted of an overhead

transmitting antenna 110 miles long, grounded at both ends, with a transmitter connected at its center. It was operated from 1963 through 1970. No changes which could be related to ELF radiation were observed in species composition of the pine forests. (Ref. 2).

In another study, ten subjects were confined for periods up to seven days during which they were exposed to a low intensity magnetic field of .0001 Wb/m^2 at 45 Hz for periods up tc 24 hours. Five subjects were confined but not exposed. A large battery of psychophysiological tests were administered throughout the confinement period. No effects were seen that could definitely be linked with the magnetic field; however, serum triglycerides in most subjects appeared to be affected by some factor associated with the experiment. In nine of ten exposed subjects it reached a maximum value 24 to 48 hours after the ELF field exposure. Similar trends were not seen in any of the five control subjects. The number of subjects is too small, however, to exclude other possible causes such as reaction to forced changes in personal living habits, modified activity, and so forth. (Ref. 24).

A study was conducted over a 42 month period by staff members of Johns Hopkins Hospital. They observed linemen subjected to 60 Hz high voltage ac fields. Some of the eleven maintenance men worked barehanded from aerial buckets connected to an energized conductor. The following facts were developed:

a. Nc X-ray radiation is produced on a properly designed and constructed high voltage transmission line.

b. The currents induced in a man's body when working barehanded may reach high values if he is not

shielded.

c. These induced currents are essentially sinusoidal.

d. Rubber gloves and similar protective equipment offer no shielding from electric fields.

e. Properly designed metallic Faraday screens will protect a man working on an energized line and will reduce induced current in his body to a negligible value.

Medical findings of this study determined that the health of the eleven men was unchanged by the exposure to low frequency high voltage fields. (Ref. 29).

D. OTHER EXAMPLES

The Biomedical Research Laboratory at the Naval Weapons Laboratory has a very broad program of research on the biological effects of nonionizing radiation. In addition to studies of effects of continuous wave and pulsed wave radiation, a major portion of the effort is devoted to the effects of high peak power electromagnetic pulses.

Electromagnetic pulse radiation, EMP, is radiation of very high power, extremely short duration pulses. They have fast rise to peak times, on the order of a few nanoseconds, producing peak field strengths up to the megavolt per meter range, exponential decay times on the order of 500 nanoseconds, and slow repitition rates of a few pulses per second. The average power output is rather small, however. The frequency spectrum of these high voltage generators is very broad, spanning from dc to approximately 80 MHz.

It is generally agreed that there are presently no applicable safety standards for high energy electromagnetic pulses. The standard may consist of average power limits, peak power limits, pulse repitition rate limits, or all three in some combination. The 10 mW/cm^2 standard for microwave exposure is not applicable to high peak power, low average power lower frequencies associated with this type system.

The biomedical studies include a medical surveillance program, behavioral and psychological studies, and basic experimental animal investigations. The medical surveillance program includes approximately 100 personnel occupationally exposed to various type pulses. The behavioral and psychological studies are based primarily on measurement of intrinsic biological timing mechanisms and are applicable to both experimental animals and human subjects. Animal studies include long-term low-dose exposures with observations on reproduction, life span, ageing, and genetics. It is also planned to study such basic systems as membrane function and enzyme kinetics. (Ref. 22).

VII. MEASUREMENT TECHNIQUES AND DIFFICULTIES

A considerable amount of confusion has arisen and many erroneous conclusions may have been drawn because of the lack of knowledge of the internal field distributions which produce effects in an animal or individual. Some scientists feel that too much emphasis is being placed on relating biologic effects in a test animal to an incident or free field power flux density in a test chamber. As a result, the absorbtion, diffraction, and scattering effects of the subject in the field are not accounted for in most cases.

It would be pointless to legislate a limit of exposure which cannot be enforced for lack of accurate measuring devices in many varying situations. Hazards cannot be assessed if they cannot be quantified. The selection of an appropriate measuring antenna for one source may not produce meaningful information regarding the field intensity from another source, located elsewhere, but operating on the same frequency. This introduces the question of spectrum integration for determining the total exposure power density for given frequency bands. Even though the local broadcast stations offer relatively more intense exposure than the HF portion of the spectrum, on an individual signal basis the bandwidth involved is more than 25 times greater in the HF area than in the AM broadcast band. Consequently, to obtain an accurate measure of the relative exposure level in these two bands, spectral power density integration is necessary. This concept holds for the entire electromagnetic spectrum. (Ref. 36).

A study to determine the effects of low intensity

microwave radiation on man has been conducted using a vertically and horizontally polarized signal at a frequency of one gigahertz. Maximum intensity of the incident wave on the human subject was .05 mW/cm^2. In both cases the radiation formed a standing wave in space on the illuminated side and pronounced shadows on the opposite side. Field intensities from the reflected waves varied from zero to as much as three times the incident value. It is apparent that one man can considerably affect the field incident on a neighbor. Therefore, measurements made for safety monitoring in the vicinity of personnel may be subject to misinterpretation if the standing waves and shadows are not taken into consideration. The positioning of a personal dosimeter is frequency dependent as a result of wave combinations, so a careful appraisal of the significance of dosimeter readings should be made in safety monitoring. (Ref. 25).

A possible approach to avoid these criticisms is to quantify the actual fields or absorbed energy in the tissue and then relate these findings to the biologic effects that may occur. Once this has been done, the next step would be to determine what incident power or outside field will produce the same effect in man. The essentials to know are what level of power per unit volume or mass absorbed by the tissue in an animal will yield an effect, and what level of power as measured by a survey meter, will produce the same absorbed power in human tissue.

These questions can be answered only through the application and development of new measurement techniques. Sensors are needed for measuring the fields and temperatures in the tissues without modifying the fields being evaluated. Without this ability, it will remain difficult to determine whether an observable effect is thermal or non-thermal in

origin, or if it is merely due to the nature of the experimental methodology. (Ref. 11). Additionally, exposure facilities such as cavities and instrumentation involving metal leads used frequently in the past can produce fields in the tissue far greater than one would expect from simple extrapolations of field measurements made in the incident wave or in the subject's immediate surroundings. Conversely, the effects of the fields on the instrumentation must be considered. (Ref. 21).

Exposure to RF sources at frequencies lower than the microwave bands has received relatively little attention. As a result, a reasonable question has been raised regarding the possible harmful effects of the radio background to which we are exposed each day of our lives. This background, in any particular geographic location, represents the spectrum of signals emitted by various radio and televisicn stations that are incident at that location. The lack of well-defined methods for such environmental measurements suggests the need for new types of isotropic sensing antennas that offer adequate system sensitivity, automated spectrum analyzing instrumentation, and carefully evaluated field measurement techniques. Recent breakthroughs in these areas include broadband power density survey meters designed for relatively high intensity microwave and other RF fields, and the use of high-sensitivity spectrum analyzers. A completely automated monitoring system which utilizes computers to control spectrum analyzers and several spiral antennas, all outfitted in a mobile facility, is currently being developed by the Department of Commerce's Office of Telecommunications. (Ref. 36).

VIII. CURRENT RESEARCH PROJECTS

There is a federal multiagency program to evaluate the biological effects of nonionizing electromagnetic radiation in the C-3000 GHz spectrum. The Office of Telecommunications Policy in the Executive Office of the President is responsible for overall coordination.

A. OBJECTIVES

This program for control of electromagnetic pollution of the environment has three objectives:

1. to determine what effects these radiations have on living organisms under varying conditions of exposure.
2. to determine the clinical significance associated with any observed effects and assess the potential hazards with respect to realistic exposure environments.
3. tc establish a sound scientific basis for appropriate remedial and/or control measures which may be warranted.

Principal areas of concern in the national program include:

- genetics
- nervous system
- behavioral studies
- general health
- mechanisms of interaction with living organisms
- ocular effects
- metabolism, endocrinology and biochemistry

instrumentation, measurement techniques and facilities
absorbtion and dosimetric studies
environmental and safety studies

The federal program presently consists of approximately 106 projects. This includes 56 being conducted within the government's own laboratories. The Navy has several internal investigative programs including those at the Naval Medical Research Institute at Bethesda; the School of Aerospace Medicine at Pensacola; the Naval Air Development Command at Warminster, Pennsylvania; the Naval Weapons Laboratory at Dahlgren, Virginia; and the Armed Forces Radiobiological Research Institute at Bethesda. In addition, the Office of Naval Research supports a number of programs at civilian universities and other institutions. (Ref. 3).

One of the main objectives of the Navy Electromagnetic Radiation Bioeffects Program is to establish safe exposure power levels and tolerance times for personnel working around communications and radar equipment. Considerable emphasis is being placed on the nervous system, both central and autonomic.

B. MICROWAVES

Work is underway to develop microwave exposure facilities covering an expanded range of RF-microwave frequencies. For example, state-of-the-art technology is being used to develop a miniature broadband probe which can be implanted within biological specimens to measure field strength.

C. VLF/ELF

ELF electric and magnetic field exposure over several weeks is under investigation. The synergistic action of two experiences, such as the resistance to infectious disease coupled with ELF radiation, is being evaluated using pneumonia and influenza models.

A long term, low exposure level study using primates is planned. The animals will be exposed continuously for one year to 45 Hz magnetic and electric fields of two gauss and 20 V/m. At the end of one year, half of the animals will be be sacrificed in both the control and experimental groups and extensive pathological studies will be performed. The remaining animals will be examined every three months for two more years.

A thorough study of the influence of 45 and 75 Hz fields on body temperatures in mice has been completed for the Navy. In field strengths of up to ten V/m and two gauss, no significant change in temperature rhythm was found even after three months of continuous exposure.

In the VLF range, studies recently completed for the Air Force revealed none of the usual indicators of pathology. This implies there is no effect from high VLF field strengths on humans. This study was conducted using 15 KV/m and 7.5 Amps/m at 25 KHz.

The Environmental Protection Agency has initiated efforts to measure and assess the fields associated with very low frequency power transmission lines. In the past most of the research in this area has been conducted by the

Russians. In the future the Energy Research and Development Agency and the power industry's own Electric Power Research Institute will investigate the issue.

D. FUTURE DIRECTION

Topics most frequently discussed at professional gatherings include the fact that the maximum permissible power density levels allegedly used by the Soviets are two to three orders of magnitude lower than those used by the United States; the possibility that certain biological factors may not have received sufficient attention when the level was established; the absence of standardization in the hazard calculation and measurement techniques; the many unanswered questions which have arisen in connection with the observed biological effects and the reported clinical manifestations resulting from exposure to nonionizing radiation. (Ref. 9).

There is work in progress in the neural/behavioral area with reasonable diversity of approaches. The mechanisms, specific exposure conditions and health implications are not yet sufficiently understood, so considerably more research is required. These areas include:

long-term exposure of at least a year's duration.

separation of effects of electric (E) and magnetic (H) fields.

modulated/pulsed radiations and comparative studies of different modulations and waveforms.

multi-frequencies exposure.

more work in neurochemistry.

dosimetry and energy distribution to permit extrapolation from animals to man. (Ref. 41).

IX. CONCLUSIONS

A natural background of electromagnetic energies exists in our environment to which all living things adapt in order to survive. To this normal state man has added additional energy. Living organisms must respond to this increased exposure as best they can within their own reserve capabilities. There is a point, however, where the capacity for response is exceeded, and the radiation source becomes a hazard. The risk can be controlled by determining standards of exposure, based upon the extent to which the effects are dangerous to the organism. (Ref. 44).

The use of microwave radiation in domestic ovens, industrial processing, medical diathermy, as well as communications and radar systems, will continue to increase in the future. As a result, the possibility for larger segments of the population to be exposed to complex microwave fields is enhanced. Therefore, it is essential that safe exposure levels be determined in order to protect individuals from harmful effects, but at the same time not to restrict unduly the beneficial uses of microwave radiation. (Ref. 19). A true hazard evaluation will not be possible until effects are identified, thresholds defined and accepted universally, and the relationships between the degree of effect to frequency, power density, and exposure as a function of time are known with certainty. (Ref. 7).

There is a possibility of suffering an increased exposure by microwave reflection in a complex environment. A high concentration of energy can occur at an unsuspected point because of the ability of microwaves to be reflected

from many types of surfaces. This can be of particular importance in close quarters, as aboard ship, where several radars are operating. (Ref. 5).

Unfortunately, the results of animal experimentation cannot validly be extrapolated to man. For example, there is no reason to think that the human eye possesses a special immunity to the effects of microwaves, but there is no information as to whether this radiation offers a greater or a lesser hazard to it than to a rabbit eye. It is not yet known how the human eye interacts with the microwave field or how its response to irradiation may be affected by field perturbations caused by the human head.

As of now, there has not been a case in which microwave radiation has been the proven cause of a human cataract. The fact that a man develops cataracts and that at some time earlier in his life he may have been exposed to microwaves does not automatically establish a cause and effect relationship. This is not to deny the possibility that they could have played a role, but it is simply to point out that the supporting evidence which has been offered does not necessarily lead to that conclusion. (Ref. 4).

Considering the ever-increasing applications of this energy form by both military and civilian users, reliable reports are relatively few. In fact, many findings are more contradictory than corroborative. Many reports are inadequate for forming meaningful conclusions concerning which biological effects are causing reversible or irreversible damage to humans. Although it is widely accepted that the production of heat is one way, if not the only way, microwaves affect humans, there exist the alleged non-thermal interactions which must continue to be investigated.

Quantitative determination of ambient radio-frequency and microwave exposure levels is currently a topic of great interest to individuals concerned with the possible health implications of this form of electromagnetic radiation. Due to a lack of definitive measurements on background levels, several fundamental problems persist:

a. Without good basic information about typical environmental levels of wave energy experienced by the general populace, it is difficult to efficiently design biological effect experiments which practically relate to day-to-day type exposures.

b. The interpretation of present day biological research is encumbered due to an incomplete picture of the electromagnetic environment in terms of its amplitude, frequency, and time history characteristics.

c. With the ever increasing use of sophisticated electronics in critical situations (cardiac pacemakers, electronic ignition and braking systems, collision avoidance equipment, and so forth) and an apparent increase in their susceptibility to interference, it is important to understand the nature of the electromagnetic environment in which these sensitive devices must reliably operate. (Ref. 40).

X. RECOMMENDATIONS

A. WARSAW SYMPOSIUM

A symposium was held in Warsaw, Poland in 1973 under the joint sponsorship of the World Health Organization and various governments. It brought together for the first time scientists and program directors from sixty countries known to have research interests in the relationship of microwave radiation to health. Several recommendations were developed at the meeting as a result of the apparent genuine interest and concern of the delegates. The general recommendations relate to four areas:

1. promotion of international coordination of research on the biologic effects of microwave radiation by continuing exchange of information, improved translation services, exchange visits, and closer collaboration in research projects and publications;

2. development of a program by an international health agency which could exert leadership and facilitate communication;

3. establishment of internationally acceptable nomenclature and definitions of physical quantities and units, and standardization of measurement techniques and dosimetry;

4. furtherance of multi-disciplinary studies to improve understanding of interactions of microwave radiation with biologic systems and to clarify risks associated with exposure. (Ref. 34).

B. SPECIFIC RECOMMENDATIONS

1. Educate physicians in occupational areas of responsibility regarding known and potential hazards.

2. Implement programs in industry and the military for safety instruction, personal dosimetry, as well as monitoring of high risk personnel.

3. Keep detailed records regarding personnel exposure. Personnel should be evaluated at regular intervals, with attention paid to psychopathology, medical, genetic, and medication history. Thorough examinations should be performed over a period of time to observe any chronic effects. These examinations are necessary to identify which subtle effects may be present, and to assess the hazard potential of these effects relative to exposure history. (Ref. 44).

4. Conduct more research on the interaction of microwaves with tissues and cells in various animal systems. In all these studies, the mechanisms of the interaction must be determined. The biological effect must also be interpreted in terms of its hazard potential to man and his environment. (Ref. 20).

5. Determine the effects of physical characteristics of an exposed individual, in addition to external factors such as temperature, humidity and air currents, on his tolerance to electromagnetic fields.

6. The synergistic effect of multiple electromagnetic sources, both ionizing and nonionizing, should be investigated further. (Ref. 11).

7. An urgent need that exists for all countries which make extensive use of electromagnetic energy is a quantitative data base on which to evaluate the biologic hazards of electromagnetic fields to man. Though several thousand papers in the literature pertain to the subject, so much of the reported data is so qualitative in nature that more questions have been raised than answered. New research is needed based on a quantitative approach from both a physical and a biologic science standpoint.

C. PROTECTIVE CLOTHING

In the immediate near term, there is something which can be done for topside personnel aboard ship and for people at radar/ communications facilities ashore who are routinely exposed to EMR. Their health and welfare is at stake while the scientific debate about possible ill effects continues.

Several researchers have concluded that when exposure cannot be avoided, it is very beneficial to wear protective garments. (Refs. 9, 26, 45, 46). This includes headgear, goggles and coveralls to reflect the incident waves.

After testing several types of suits, the Navy determined that heavy duty nylon impregnated with silver provides the most safety over the frequency range from 200 MHz to 10 GHz in field intensities up to 200 mW/cm^2.

Goggles with lens possessing a metallic film coating or micromesh screen are effective from 1 - 10 GHz. However, below that, radiation directed at the back of the head would penetrate to the eyes. Therefore, a wire mesh headgear, similar to that worn by fencers, would be required.

It is granted that these measures are cumbersome and would meet fierce resistance from most people. However, just as personnel working near sources of nuclear and X-ray radiation wear appropriate protective garments, so too should affected Navy personnel. Until an undeniable conclusion is reached that nonionizing EMR is not harmful, it is wiser to take sensible precautions.

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